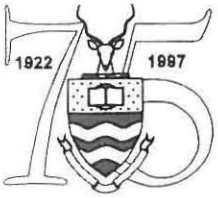
The effect of simulated harvesting on biomass and agar of *Gelidium abbottiorum* R.E. Norris at Reunion Rocks, KwaZulu-Natal, South Africa



J. Aingworth and A.T. Critchley*

Department of Botany, University of the Witwatersrand, Private Bag 3, Wits, 2050, Republic of South Africa

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The effect of simulated harvesting on the biomass and agar content and quality of *Gelidium abbottiorum* was investigated at Reunion Rocks, KwaZulu-Natal for the period July 1995 to July 1996. There are no previous published records of biomass assessment for seaweeds on the KwaZulu-Natal coast, many of which are of potential economic value. Seaweed samples were collected from Reunion Rocks every three months. This included harvesting the seaweed using two methods, i.e. 'plucking' and 'shearing'. Biomass was assessed and dry mass values of 255–384 $g.m^{-2}$ were recorded for the period July 1995 to July 1996. No seasonal differences in biomass were found for the period July 1995 to July 1996. Standing stocks in commercial beds elsewhere in the world vary from 0.5–1.5 $Kg.m^2$ fresh mass. The fresh mass of *Gelidium abbortiorum* was between 0.9–1.4 $Kg.m^{-2}$. Therefore, it was concluded that biomass was comparable to that in commercial beds in other areas of the world. Both harvesting methods had the effect of decreasing the biomass over the study period (i.e. from July 1995 to July 1996). It is recommended that 'plucking' be used as a harvesting method if harvesting is to occur at this site. It is suggested that harvesting take place once a year either in spring (September–December) or summer (January–March). Agar was extracted and the quality tested, i.e. gel strength, gelling temperature and melting temperature. Mean agar yields of between 17.5–36.6% were obtained. Gel strength of agar was measured to be between 64.9–291.2 $g.cm^{-2}$. Gelling temperatures of between 26–34.7°C were recorded. Melting temperatures of the agar were between 66–77.1°C. There was no seasonal difference in any of the agar characteristics. It was concluded that agar from this source could be used commercially, if blended with superior material from other sources.

Keywords: resource assessment; *Gelidium abbottiorum*; South Africa; seaweed biomass; harvesting; agar; phycocolloids; agarophyte.

*To whom correspondence should be addressed.

Introduction

The coast of KwaZulu-Natal, South Africa has a diverse marine flora for which little attention to management/conservation strategies, excluding Natal Parks' Board Marine Reserves, has been paid. To date, no attention has been paid to stock assessment, harvesting strategies or demography of this algal resource, although several comprehensive studies concerning the assessment of algal occurrence and biogeography have been carried out along this coastline (Farrell *et al.* 1993, 1994). At present, there is no activity (commercial or otherwise) relating to the use of the rich marine floral resource of KwaZulu-Natal.

The east coast of southern Africa is influenced by warm temperate waters (Lüning *et al.* 1990); the Mozambique Current in the north and the Agulhas Current in the south (Stephenson *et al.* 1936). The Agulhas Current extends from Cape Agulhas along the southern and eastern coasts of South Africa to southern KwaZulu-Natal (Lüning *et al.* 1990). The mean seawater temperature along the KwaZulu-Natal coast is reported in the range of 17–19°C, with ranges for the means of 19°–21°C in the warmest month and 13°–17°C in the coldest month (Lüning *et al.* 1990).

Published works on the marine flora of KwaZulu-Natal are summarised by: Stephenson and Stephenson (1972, on zonation), the taxonomic works of Norris (1987, 1990, 1992) and the biogeographic data analysed by Farrell *et al.* (1993, 1994).

This paper describes the biomass, productivity and agar properties of harvested *Gelidium abbottiorum* R. E. Norris (Rhodophyta, Gelidiales; previously *G. amansii sensu* Siegrief), a dominant, easily accessible alga of the intertidal zone at Reunion Rocks, KwaZulu-Natal (29°E, 21°S). This study site was selected after a survey of the KwaZulu-Natal coastline. *G. abbottiorum* is a well known source of high quality agar (Macler & West 1987) around the world and is presently harvested in the former Transkei and from the coast of the Eastern Cape Province, South Africa (Anderson *et al.* 1991). Its potential for utilization as an economic resource in KwaZulu-Natal is reported on here.

Materials and Methods

Study site

Reunion Rocks (29°E, 21°S) was selected as a practical study site, being readily accessible for ease of sampling and, further to a more extensive survey (Aingworth 1996; Gillespie *et al.* 1997), as being reasonably representative of the KwaZulu-Natal marine flora.

Sample size and number

Optimal quadrat size was determined as 300 × 300 mm from a minimal area curve. Sampling intensity was set at 15 quadrats such that the standard error of the mean remained below 15% and could be completed during a three hour low tide period.

Biomass assessment

In order to estimate wet weight standing stock of *Gelidium abbottiorum*, plants were completely removed from their substratum using a paint scraper, from 15 non-permanent quadrats (300 × 300 mm), taken within the *Gelidium* population. A known wet weight was dried to constant weight at 70°C (Carter 1986). Samples were collected at 3-month intervals in order to give an indication of seasonal variation which may occur in biomass (Rico 1991; Table 1). A linear relationship was found between fresh and dry mass with an 96 % goodness of fit coefficient. Fresh mass values were determined from the equation $y = 0.27x + 24.36$.

In order to facilitate comparison with values obtained from other

Table 1 Seasonal collection dates of *Gelidium abbottiorum* from Reunion Rocks, KwaZulu-Natal

Season	Date of collection
Winter 1995	11–15 July
Spring 1995	23–27 October
Summer 1996	20–23 January
Autumn 1996	3–7 April
Winter 1996	30 June–4 July

areas of the world, fresh mass values for biomass assessment of *Gelidium abbottiorum* at Reunion Rocks, KwaZulu-Natal were estimated from a calibration curve of fresh mass versus dry mass. This could be done since a linear relationship was found between fresh and dry mass as mentioned before.

Values obtained from harvesting experiments were expressed as mean dry mass (± standard error). Additionally, fresh mass was estimated from these dry mass values. No statistical analysis was performed on the fresh mass values.

Harvesting

(i) Plucking

G. abbottiorum plants from 15 permanent quadrats (300 × 300 mm, marked by brass bolts in the rock) within the intertidal zone, were plucked by hand. This involved a single 'handgrab' or 'snatch' of each tuft which resulted in removal of most upright fronds and some holdfast material (Carter 1986). Measurements were taken quarterly for one year. Samples were dried to constant weight at 70°C for dry mass determination.

(ii) Shearing

From 15 permanent quadrats (300 × 300 mm), marked as above, tufts of *G. abbottiorum* attached to the rock were cut with a pair of shears to a height of approximately 10 mm above the substratum, avoiding damage to the holdfasts (Carter 1986). Samples were taken quarterly for one year. Biomass from dry mass was determined as above.

Agar yield and quality

(i) Yield

Samples of *Gelidium abbottiorum* were collected for agar analysis every three months. Agar content was determined from three replicates using the methods of Bird and Hinson (1992) and Lemus *et al.* (1991): 10 g of oven dried material was rehydrated in distilled water for a period of approximately 30 minutes. The material was boiled under pressure (110°C; 1.21 $Kg.m^{-2}$) for 3 hours. The hot suspension was filtered through muslin cloth; the filtrate was frozen overnight and then thawed in tap water. Agar flock was removed by filtering through fine muslin cloth and dried at 45°C overnight to constant weight. Agar content was expressed as a percentage of the dry seaweed weight (Wilson 1993).

(ii) Gel quality

Gel strength, melting and gelling temperatures were determined by adding 0.75g of agar flakes to 50 ml distilled water allowing them to stand overnight and then heating using pressure (i.e. using an autoclave; 110°C, 1.21 $Kg.cm^{-2}$) for 30 minutes (Christeller & Liang 1989).

A 'standard' agar was obtained in order to facilitate comparison of study material with a commercial-grade agar (Agar-agar, Batch 38230 obtained from Saarchem-Holpro Analytic Pty (Ltd); a blend of materials used to produce a superior product). The seaweed from which the 'standard' agar was extracted was alkali pre-treated before extraction of the agar, i.e. it was soaked in an alkali solution at 70°C for about one hour before the agar was extracted. This results in a lower yield (Lemus *et al.* 1991) but a higher gel strength of the agar (K.W.G. Rotmann pers. comm.).

Gel strength was measured using the Kobe or Nikkansui measuring method with a Nikan gel strength instrument; this method measures the force that a 1.5% gel can withstand for 20 seconds at 20°C (Wilson 1993). Gel solutions were prepared as above. The gel solutions were poured into repli dishes (3.5 cm diameter; 1 cm deep), covered and allowed to stand for 15 hours at 20°C, since the gel is then at its strongest (Wilson 1993). The plunger on the Nikan apparatus was lowered over the gel surface until an indentation was made in the gel surface. Weights were added sequentially to the plunger. The time between the addition of the last weight and the point when the plunger penetrated the gel surface was recorded.

The gel strength (in $g.cm^{-2}$) was then calculated according to the equation:

$$\log W_{20} = \log W + k (\log t - \log 20)$$ (Wilson 1993)

Where W_{20} = maximum weight that could be resisted for 20 seconds at 20°C, W = weight (plunger weight + added weight resisted at time t, t = time (in seconds) resisted by gel with weight W and k = coefficient = 0.18.

Gel strength was determined for three replicates. The gelling and melting temperatures were determined for three replicates using the methods of Nelson *et al.* (1983), Hurtado-Ponce and Umezaki (1988) and Luhan (1992).

Gelling temperature

Gel solutions were prepared as above. The hot agar solution was poured into a glass vial and a thermometer was placed in the glass vial, just off centre. The solution was allowed to cool. Glass beads were dropped into the glass vial one at a time. The temperature at which the glass bead failed to penetrate the agar (i.e. remained on the surface of the agar) was considered the gelling temperature.

Melting temperature

The glass vial containing the agar was heated slowly over a bunsen burner. Glass beads were dropped into the vial. The temperature at which the bead dropped through the agar (i.e. touched the bottom of the vial) was considered the melting temperature.

Statistical analysis

All data were analysed using a one-way ANOVA. Significant differences were identified using a Multiple Comparison Tukey test. Systat version 5.03 for DOS was used for all statistical analyses.

Results and Discussion

Biomass assessment

Biomass of *Gelidium abbottiorum* was assessed for the period July 1995 to July 1996. Dry mass values of 255–384 $g.m^{-2}$ were recorded (Table 002).

Table 2 Results from biomass assessment of *Gelidium abbottiorum* from Reunion Rocks, KwaZulu-Natal for July 1995 to July 1996 (n = 15)

Date	Mean dry mass ($g.m^{-2}$ ± SE)	Fresh mass ($Kg.m^{-2}$)
July 1995	384.01 ± 50.49	1.4
October 1995	275.22 ± 57.42	1.0
January 1996	299.16 ± 64.21	1.0
April 1996	348.26 ± 54.88	1.2
July 1996	255.85 ± 52.47	0.9

There was no significant difference ($p < 0.05$) between the biomass recorded from the different sampling times using non-permanent quadrats, i.e. there was no significant seasonal difference in biomass within the period July 1995–July 1996. These results differ from those obtained for *Onikusa pristoides* (Turner) Akatsuka (as *G. pristoides*) on the Cape coast by Anderson *et al.* (1991), who indicated that there were seasonal fluctuations in biomass, being highest in late summer (January–March) and declining in late winter (July–August). This difference may be the result of the fact that there is no major seasonal fluctuation in water temperature along the KwaZulu-Natal coast (Lüning *et al.* 1990), whereas the water temperatures along the Cape coast decrease markedly in the winter months, thereby making conditions unfavourable for growth.

Standing stocks (fresh mass) in commercial beds elsewhere in the world vary widely from a few hundred grams to a maximum of 1.5 $Kg.m^{-2}$. In Japan, the fishing fields are classified as follows: excellent - if biomass of *Gelidium* is above 1.5 $Kg.m^{-2}$, good - if standing stock is between 1.0 and 1.5 $Kg.m^{-2}$, normal - if the stock is between 0.5 and 1.0 $Kg.m^{-2}$ and poor - if biomass is below 0.5 $Kg.m^{-2}$ (Santelices 1988). According to this classification, fresh mass values obtained for *G. abbottiorum* from Reunion Rocks (Table 2) ranged from normal to good for biomass assessment and poor to normal for harvested samples (Table 3).

Productivity

(i) Plucking

There was significantly less ($p < 0.05$) biomass in April 1996 (108.91 ± 36.71 $g.m^{-2}$) and July 1996 (167.21 ± 49.03 $g.m^{-2}$) than there was at the other collection periods. Therefore, repeated 'plucking' of *G. abbottiorum* at Reunion Rocks from the same area resulted in decreased productivity over the experimental period. Although the biomass in January 1996 was higher than that in October 1995, it was not significantly so.

(ii) Shearing

Permanent quadrats were subject to successive shearing over the period October 1995 to July 1996. Dry mass values of between 19.30 $g.m^{-2}$ and 111.79 $g.m^{-2}$ were recorded using this method (Table 3). Biomass was significantly higher ($p < 0.05$) in January 1996 (111.79 ± 40.48 $g.m^{-2}$) than in October 1995 (66.04 ± 14.20 $g.m^{-2}$), April 1996 (55.36 ± 25.26 $g.m^{-2}$) and July 1996 (19.30 ± 8.66 $g.m^{-2}$). Therefore, there were no seasonal differences in the productivity of *G. abbottiorum* obtained using the 'shearing' method. There was no trend of decreasing productivity of this method, as for 'plucking'.

Table 3 Results from harvesting experiments of *Gelidium abbottiorum* from Reunion Rocks, KwaZulu-Natal for October 1996 to July 1996. 'Shearing' refers to samples that were collected by repeatedly shearing the same area at three month intervals; 'plucking' refers to samples that were collected by repeatedly hand plucking the same area at three month intervals

Treatment	Date	Mean dry mass ($g.m^{-2} \pm SE$)	Fresh mass ($Kg.m^{-2}$)
Shearing	July 1995	167.25 ± 24.0	0.6
	October 1995	66.04 ± 14.2	0.2
	January 1996	111.79 ± 40.48	0.4
	April 1996	55.36 ± 25.26	0.2
	July 1996	19.30 ± 8.66	0.05
Plucking	July 1995	369.34 ± 58.4	1.3
	October 1995	249.25 ± 39.84	0.9
	January 1996	282.53 ± 72.34	1.0
	April 1996	108.91 ± 36.71	0.4
	July 1996	167.21 ± 49.03	0.6

(iii) The effect of harvesting on biomass

Dry mass values obtained from repeated 'plucking' of seaweed from permanent quadrats in October 1995 (249.25 ± 39.84 $g.m^{-2}$; Table 3) were comparable to the standing biomass in October 1995 (275.22 ± 57.42 $g.m^{-2}$; Table 1), i.e. there was no significant difference ($p < 0.05$). This indicates that productivity was equal to standing biomass in October 1995. Therefore, harvesting would be feasible at this time.

In April 1996 (348.26 ± 54.88 $g.m^{-2}$) and July 1996 (255.85 ± 52.47 $g.m^{-2}$), standing biomass (Table 2) was significantly greater ($p < 0.05$) than that obtained using either the 'plucking' (108.91 ± 36.71 $g.m^{-2}$ and 167.21 ± 49.03 $g.m^{-2}$ respectively) or 'shearing' (55.36 ± 25.26 $g.m^{-2}$ and 19.30 ± 8.66 $g.m^{-2}$ respectively; Table 3) method of harvesting. Neither method of harvesting yielded a greater biomass.

These results indicate that both harvesting methods had the effect of decreasing the biomass obtained. Initially, 'plucking' yielded more biomass than 'shearing'. However, after the first harvesting period (i.e. October 1995), there was no significant difference ($p < 0.05$) between the two methods used. Carter and Simons (1987), reported the same initial results for *Onikusa* (*Gelidium*) *pristoides* from Port Alfred, South Africa. However, repeated shearing treatments of *O.* (*G*) *pristoides* resulted in atypical prolific branching (coppicing) in the upper distal regions of the plants, therefore raising yields beyond that which would be expected from normal frond growth. However, faster regrowth after shearing has been reported for a number of *Gelidium* populations (Santelices 1988; Santos 1993), the reason being that plucking damages the holdfasts or creeping axes. The importance of avoiding damage to the holdfast has been stressed in previous studies, since damage may affect the successful maintenance of harvested seaweed stocks (Carter & Simons 1987). Shearing causes minimal damage to the holdfast, whereas plucking carries an inherent danger of damaging the holdfast region. In addition, it creates an exposed substratum, therefore making the area free for competing species to establish. This may result in a decreased population of the harvested species since competition is facilitated.

Agar yield and quality

(i) Yield

Samples taken in July 1995 were not separated into 'biomass', 'plucked' and 'sheared' samples as this was the first collection date and therefore there would be no influence of harvesting on the agar yield as yet. Similarly for gel strength, gelling temperature and melting temperature.

(a) Biomass

Agar was extracted from samples obtained from the biomass assessment of *G. abbottiorum*. Mean agar yields of between 17.5% and 29.6% dry weight were recorded (Table 4). There was significantly less ($p < 0.05$) agar yield in October 1995 ($17.5\% \pm 0.05$) and July 1996 ($21.5\% \pm 0.12$).

(b) 'Plucked'

Agar was extracted from samples obtained by 'plucking' permanent quadrats quarterly. Agar yields of between 22.1% and 26.5% dry weight were recorded for samples collected by

Table 4 Results of agar extraction from Gelidium abbottiorum from Reunion Rocks, KwaZulu-Natal. Biomass = agar extracted from samples collected for biomass assessment; Plucked = agar extracted from samples collected by hand-plucking; Sheared = samples collected by shearing

Date	Yield (% dry weight)		
July 1995	29.6 ± 0.17		
	Biomass	Plucked	Sheared
October 1995	17.5 ± 0.05	22.3 ± 0.29	36.6 ± 0.2
January 1996	26.5 ± 0.03	26.5 ± 0.19	32.5 ± 0.19
April 1996	26.0 ± 0.13	25.9 ± 0.05	21.7 ± 0.08
July 1996	21.5 ± 0.12	22.1 ± 0.12	32.1 ± 0.06

'plucking' (Table 4). Mean yields in July 1995 (29.6% ± 0.17) and July 1996 (22.1 % ± 0.12) were significantly different ($p < 0.05$).

(c) 'Sheared'

Agar was extracted from samples obtained quarterly from permanent quadrats using the shearing method. Mean agar yields of between 21.7–36.6% dry weight were recorded for samples collected by 'shearing' the seaweed to a height of ± 10mm (Table 4). Significantly more ($p < 0.05$) agar was yielded in October 1995 (36.6% ± 0.2) and significantly less ($p < 0.05$) agar was yielded in April 1996 (21.7% ± 0.08). Therefore, there was no effect of harvesting on agar yield obtained from samples collected using this harvesting method.

No seasonal variation in agar content was recorded for any of the samples analysed above. This is contrary to the findings of Carter (1985) who reported a seasonal variation with yields being highest in summer, corresponding to maximum growth. Seasonal variation in agar yield, with yield highest in summer has also been reported for other species studied, i.e. *Gelidium spinosum* (S. Gmelin) P. Silva (as *G. latifolium*, Mouradi-Givernaud *et al.* 1992), *Gracilaria pseudoverrucosa* (Lahaye & Yaphe 1988), *Gracilaria heteroclada* (Luhan 1992), *Onikusa* (*Gelidium*) *pristoides* (Onraet & Robertson 1987).

In contrast, some authors have reported lower agar yields during summer months (Bird & Hinson 1992; Oyieke 1993). According to Carter (1985), this suggests that seasonal fluctuations in agar yield and growth are influenced by different factors, depending on the area and/or species under consideration.

Agar yield from *Gelidium abbottiorum* at Reunion Rocks is such that harvesting this seaweed could be commercially viable. There was no significant difference between yields of agar whichever method of collection was employed. However, shearing is a more time-consuming method of harvesting and results in a lower biomass. Therefore, harvesters preferably employ the hand-plucking method over the shearing method (Santos 1993).

(ii) Gel quality

(a) Gel strength

Gel strength was measured for both the agar extracted from *Gelidium* collected in the field and the commercially purchased Agar-agar ('standard'). Mean gel strength was recorded as 529.5 $g.cm^{-2}$ for the 'standard' (alkali pre-treated, therefore having a low relative yield, but a relatively higher gel strength). The mean gel strength of agar from *G. abbottiorum* from KwaZulu-Natal was between 64.9–291.2 $g.cm^{-2}$ (Table 5).

(i) Biomass

The mean gel strength for agar (Table 5) from samples collected for biomass assessment of *G. àbbottiorum* was significantly higher ($p < 0.05$) in April 1996 (277.3 ± 4.47 $g.cm^{-2}$) than in October 1995 (128.3 ± 44.26 $g.cm^{-2}$) and July 1996 (115.1 ± 9.08 $g.cm^{-2}$).

(ii) 'Pluck'

The mean gel strength of agar (Table 5) from samples collected from quadrats that were repeatedly plucked was significantly lower ($p < 0.05$) in July 1996 (64.9 ± 6.53 g.cm-*2*) than at any other sampling time.

(iii) 'Shear'

The mean gel strength of agar (Table 5) from samples collected from quadrats that were repeatedly sheared was significantly higher ($p < 0.05$) in July 1995 (194.3 ± 45.46 $g.cm^{-2}$) than in October 1995 (138.1 ± 5.81 $g.cm^{-2}$), April 1996 (175.9 ± 12.64 $g.cm^{-2}$) and July 1996 (126.2 ± 0.77 $g.cm^{-2}$).

No seasonal variation was recorded in gel strength of agar. A number of authors have reported seasonal variations in gel strength from various red seaweed species (Onraet & Robertson 1987; Hurtado-Ponce & Umezaki 1988; Bird & Hinson 1992; Luhan 1992; Mouradi-Givernaud *et al.* 1992; Yengiul 1993).

Generally, gel strength is the most important quality parameter of agar and is used to distinguish between the strong, brittle gels which have biotechnological applications, and the soft, elastic gels which are used in the food industry (Onraet & Robertson 1987). Therefore, in terms of gel strength, the agar from Reunion Rocks is not a good bacteriological source of agar since the gel of all agars considered in this study is soft and elastic, but could be a source of agar for the food industry.

(b) Gelling temperature

Mean gelling temperature for the 'standard' was recorded to be

Table 5 Mean gel strength ($g.cm^{-2}$ ± SE) of agar from *Gelidium abbottiorum* from KwaZulu-Natal. Gel strength of the 'standard' was recorded as 529.5 $g.cm^{-2}$

Date	Biomass samples	Plucked samples	Sheared samples
July 1995	194.3 ± 45.46	194.3 ± 45.46	194.3 ± 45.46
October 1995	128.3 ± 44.26	201.6 ± 11.52	138.1 ± 5.81
January 1996	189.1 ± 7.18	242.5 ± 14.72	291.2 ± 3.58
April 1996	277.3 ± 4.47	249.8 ± 25.83	175.9 ± 12.64
July 1996	115.1 ± 9.08	64.9 ± 6.53	126.2 ± 0.77

Table 6 Mean gelling temperature (°C ± SE) of agar from *Gelidium abbottiorum* from KwaZulu-Natal. Gelling temperature of 'standard' = 39.0° C ± 0.49

Date	Biomass samples	Plucked samples	Sheared samples
July 1995	34.7 ± 0.69	34.7 ± 0.69	34.7 ± 0.69
October 1995	28.9 ± 1.10	30.4 ± 0.68	30.7 ± 5.81
January 1996	31.8 ± 0.75	30.3 ± 0.80	31.8 ± 0.83
April 1996	31.6 ± 0.30	30.6 ± 0.47	31.3 ± 0.87
July 1996	30.0 ± 0.47	26.0 ± 0.57	29.1 ± 0.61

Table 7 Mean melting temperature (°C ± SE) of agar from *Gelidium abbottiorum* from KwaZulu-Natal. Melting temperature of 'standard' = 79.0°C ± 3.18

Date	Biomass samples	Plucked samples	Sheared samples
July 1995	72.5 ± 2.10	72.5 ± 2.10	72.5 ± 2.10
October 1995	66.5 ± 1.44	71.6 ± 1.85	75.0 ± 3.45
January 1996	69.0 ± 4.63	71.0 ± 0.81	72.5 ± 3.72
April 1996	73.2 ± 1.90	77.1 ± 2.00	72.2 ± 1.94
July 1996	69.5 ± 4.77	70.7 ± 3.22	66.0 ± 2.46

39.0°C ± 0.49. Mean values for agar from *G. abbottiorum* from KwaZulu-Natal ranged between 26.0°C to 34.7°C (Table 6).

The United States Pharmacopeia standards require agars that have a gelling temperature between 32–39°C (Hurtado-Ponce & Umezaki 1988; see also Armisen 1995). According to this standard, many agars from various sources around the world as well as that from Reunion Rocks would be rejected as a sole commercial source of agar. However, commercial agars are blends of a number of agar sources and the agar from *G. abbottiorum* from Reunion Rocks could be considered as a potential commercial source blended together with other agars.

(c) Melting temperature

Mean melting temperature for the 'standard' was recorded as 79.0°C ± 3.18. Mean melting temperature for agar from *G. abbottiorum* from KwaZulu-Natal ranged between 66.0°C and 75.0°C (Table 7).

No significant difference ($p < 0.05$) was found for the mean melting temperature of agar from samples collected for biomass assessment of *Gelidium abbottiorum*, samples collected by repeatedly plucking the same area or for samples collected by shearing the same area at each sampling time. Therefore, there was no seasonal difference in melting temperature for *G. abbottiorum* from Reunion Rocks, KwaZulu-Natal. Bird and Hinson (1992) reported little seasonality for melting temperatures of agar from *Gracilaria blodgetti*, *Gracilaria tikvahiae* and *Gelidium pusillum*. Besides this, there are no reports of seasonal variations in melting temperature.

The agar from all samples except that collected for biomass assessment of *G. abbottiorum* was comparable to the 'standard' . However, the United States Pharmacopeia would reject these agars, including the 'standard', since they require that agars do not melt below 85°C (Hurtado-Ponce & Umezaki 1988). Melting temperatures of agars from around the world mostly satisfy this requirement (see Armisen 1995).

Conclusions

If *Gelidium abbottiorum* is to be exploited at Reunion Rocks, KwaZulu-Natal, a management plan geared towards the long-term maintenance of this resource needs to be formulated. Although it has been reported that harvesting by 'shearing' is a possible means of preventing harm to the holdfast and therefore increasing productivity, this has proven not to be the case (Carter 1986). 'Shearing' is more time consuming and therefore more expensive since a greater labour force would be required for harvesting. It is suggested that if *Gelidium abbottiorum* is harvested at Reunion Rocks, it should be by the 'plucking' method (i.e. grabbing the seaweed by hand and pulling it off the rock) since this method is the most cost-efficient in terms of time and money spent on labour.

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References

AINGWORTH, J. 1996. An investigation of the effect of harvesting on the biomass and agar yield from *Gelidium abbottiorum* from Reunion Rocks, KwaZulu-Natal, South Africa. MSc Thesis. University of the Witwatersrand, South Africa.

ANDERSON, R.J., SIMONS, R.H. & JARMAN, N.G. 1989. Commercial seaweeds in South Africa: A review of utilization and research. *S Afr. J. Mar Sci.* 8: 277–299.

ANDERSON, R.J., SIMONS, R.H., JARMAN, N.G. & LEVITT, G.J. 1991. *Gelidium pristoides* in South Africa. *Hydrobiologia* 221: 55–66.

ARMISEN, R. 1995. World-wide use and importance of *Gracilaria*. *J Appl. Phycol.* 7: 231–243.

BIRD, K.T. & HINSON, T.K. 1992. Seasonal variations in agar yields and quality from North Carolina agarophytes. *Bot. Mar.* 35: 291–295.

CARTER, A.R. 1985. Reproductive morphology and phenology, and culture studies of *Gelidium pristoides* (Rhodophyta) from Port Edward in South Africa. *Bot. Mar.* 28: 303–311.

CARTER, A.R. 1986. Studies on the Biology of the Economic Marine Red Alga *Gelidium pristoides* (Turner) Kuetzing (Gelidiales: Rhodophyta). PhD Thesis, Rhodes University, South Africa.

CARTER, A.R. & SIMONS, R.H. 1987. Regrowth and production capacity of *Gelidium pristoides* (Gelidiales, Rhodophyta) under various harvesting regimes at Port Alfred, South Africa. *Bot. Mar.* 30: 227–231.

CHRISTELLER, J.T. & LIANG, W.A. 1989. The effect of environment on agar and gel characteristics of *Gracilaria sordida* Nelson (Rhodophyta). *Bot. Mar.* 32: 447–455.

FARRELL, E.G., CRITCHLEY, A.T. & AKEN, M.E. 1993. The intertidal algal flora of Isipingo Beach, Natal, South Africa and its phycogeographical affinities. *Helgol. Meeres.* 47: 145–160.

FARRELL, E.G., CRITCHLEY, A.T., AKEN, M.E. & PIENAAR, R.N. 1994. The biogeographical affinities of the seaweed flora of Natal, South Africa, as typified by Isipingo Beach: A multivariate approach. *Bot. Mar.* 36: 277–285.

GILLESPIE, R.D., AINGWORTH, J. & CRITCHLEY, A.T. 1997. The seaweed resources of KwaZulu-Natal, South Africa: The current state of our knowledge. In: Current Trends in Marine Botanical Research in the East African Region, eds. M. Bjork, A.K. Semesi, M. Pedersen and B. Bergman, pp 186–193. S.I.D.A. Sweden.

HURTADO-PONCE, A.Q. & UMEZAKI, I. 1988. Physical properties of agar gel from *Gracilaria* (Rhodophyta) of the Philippines. *Bot. Mar.* 31: 171–174.

LAHAYE, M. & YAPHE, W. 1988. Effects of season on the chemical structure and gel strength of *Gracilaria pseudoverrucosa* agar (Gracilariaceae, Rhodophyta). *Carbohydrate Polymers* 8: 285–301.

LEMUS, A., BIRD, K., KAPRAUN, D.F. & KOEHN, F. 1991 Agar yield, quality and standing crop biomass of *Gelidium serrulatum*, *Gelidium floridanum* and *Pterocladia capillacea* in Venezuela. *Food Hydrocolloids* 5 (5): 469–479.

LUHAN, M.R.J. 1992. Agar yields and gel strength of *Gracilaria heteroclada* collected from Iloilo, central Philippines. *Bot. Mar.* 35: 169–172.

LÜNING, K., YARISH, C. & KIRKMAN, H. 1990. Seaweeds: Their Environment, Biogeography, and Ecophysiology. English language edition edited by: Yarish, C. & Kirkman, H. John Wiley & Sons, Inc., New York.

MACLER, B.A. & WEST, J.A. 1987. Life history and physiology of the red alga, *Gelidium coulteri*, in unialgal culture. *Aquaculture* 61: 281–293.

MOURADI-GIVERNAUD, A., GIVERNAUD, T., MORVAN, H. &

COSSON, J. 1992. Agar from *Gelidium latifolium* (Rhodophyceae, Gelidiales): Biochemical composition and seasonal variation. *Bot. Mar.* 35: 153–159.

NELSON, S.G., YANG, S.-S., WANG, C.-Y. & CHIANG, Y.-M.1983. Yield and quality of agar from species of *Gracilaria* (Rhodophyta) collected from Taiwan and Micronesia. *Bot. Mar.* 26:361–366.

NORRIS, R.E. 1987. *Pterocladia* (Gelidiaceae, Rhodophyceae), a genus previously unknown in South Africa, as it occurs in Natal. *S. Afr. J. Bot.* 53: 39–43.

NORRIS, R.E. 1990. A critique on the taxonomy of an important agarophyte, *Gelidium amansii*. *Jpn. J. Phycol.* 38: 35–42.

NORRIS, R.E. 1992. The Marine Red Algae of Natal, South Africa: Order Gelidiales (Rhodophyta). National Botanical Institute, Claremont, South Africa. 43pp.

ONRAET, A.C. & ROBERTSON, B.L. 1987. Seasonal variation in yield and properties of agar from sporophytic and gametophytic phases of *Onikusa pristoides* (Turner) Akatsuka (Gelidiaceae, Rhodophyta). *Bot. Mar.* 30: 491–495.

OYIEKE, H.A. 1993. The yield, physical and chemical properties of agar gel from *Gracilaria* species (Gracilariales, Rhodophyta) of the Kenya coast. *Hydrobiologia* 260/261: 613–620.

RICO, J.M. 1991. Field studies and growth experiments on *Gelidium latifolium* from Asturias (northern Spain). *Hydrobiologia* 221: 67–75.

SANTELICES, B. 1988. Synopsis of biological data on the seaweed genera *Gelidium* and *Pterocladia* (Rhodophyta). *F.A.O. Fisheries Synopsis* 145: vi + 55pp.

SANTOS, R. 1993. Plucking or cutting *Gelidium sesquipedale*? A demographic simulation of harvest impact using a population projection matrix model. *Hydrobiologia* 260/261: 269–276.

STEPHENSON, T.A., STEPHENSON, A. & DU TOIT, C.A. 1936. The South African intertidal zone and its relation to ocean currents. *Trans. Royal Soc. S. Afr.* 24: 341–382.

STEPHENSON, T.A. & STEPHENSON, A. 1972. Life Between Tidemarks on Rocky Shores. 425p. W.E. Freeman and Co., San Fransisco.

WILSON, A.J. 1993. The influence of selected environmental parameters on the growth and agar production of *Gracilaria* sp. and *Gracilaria aculeata* (Rhodophyta). MSc thesis, University of the Witwatersrand, Johannesburg, South Africa.

YENIGAL, M. 1993. Seasonal changes in the chemical and gelling characteristics of agar from *Gracilaria verrucosa* collected in Turkey. *Hydrobiologia* 260/261: 627–631.